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HUMAN ADAPTATIONS IN THE ANDES: A LOOK AT NUTRITION AND BRAIN FUNCTION WITH RESPECT TO COCA AND HIGH ALTITUDE PHYSIOLOGICAL ADAPTATIONS

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HUMAN ADAPTATIONS IN THE ANDES: A LOOK AT NUTRITION AND BRAIN FUNCTION WITH RESPECT TO COCA AND HIGH ALTITUDE PHYSIOLOGICAL ADAPTATIONS

by

Barrett P. Brenton

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INTRODUCTION

Throughout the span of human evolution the brain has allowed itself to be controlled by nutritional intake. This correlation between nutrition and the brain has led me to believe that the human brain has allowed itself to be maniputlated and controlled by an individual's dietary intake in order to successfully adapt to the environment. In looking at the indigenous peoples of the South American Andes, I found surprising parallels between human physiological adaptations to high altitude hypoxia and cold stres and the correlating control of neurotransmitters to the brain by dietary intake.

In a study of this type it becomes necessary to first break the barriers of scientific jargon and give a brief overview of th biochemical aspects involved in the study of nutrition and the brain. Within the context of this paper I have chosen to deal primarily with the neurotransmitter, serotonin, and its percursor tryptophan, due to their possible correlations with high altitude adaption.

BIOCHEMICAL ASPECTS OF TRYPTOPHAN AND SEROTONIN

Tryptophan is an amino acid produced only by the digestion o proteins. It is an "essential" amino acid and is required for no growth and development. However, it is the least abundant of the amino acids in most dietary proteins.

The amino acid tryptophan is converted from acid to amine by two enzymes contained in the serotonin utilizing brain neurons. The first step in this process involves the mono-oxygenation (the addition of one oxygen molecule) of tryptophan to 5-hydroxytryptophan (5HTP) through the catalytic action of the enzyme tryptophan-5-hydroxylase. This is followed by the decarboxylation to serotonin (5-hydroxytryptamine) by the enzyme aromatic-L-amino acid decarboxylase (Hayaishi 1980). Tryptophan hydroxylase catalyses the rate-limiting step in serotonin synthesis. For this reason attention has focused on tryptophan hydroxylation as the probable site for the overall regulation of serotonin formation (Fernstrom 1981).

Serotonin, when released into synapses as a neurotransmitter or into the extracellular space of the brain, has been attributed to having an affect on physiological activities of the brain neurons, including those involved in modulating the brain's sensitivity to environmental inputs; controlling appetite, sexual, and aggressive behaviors; sustaining mood; directing the secretion of some pituitary hormones; control of thermo-regulation in teh hypothalumus; affecting blood pressure and hypertension; and generating rhythms in sleep-wakefulness and other cyclic neural phenomena (Wurtman 1980).

NUTRITIONAL CONTROL OF BRAIN TRYPTOPHAN AND SEROTONIN

The conversion of tryptophan into serotonin is influenced by the proportion of carbohydrate in the diet. The synthesis of of serotonin in turn affects the proportion of carbohydrates an individual subsequently chooses to eat, but not the amount of protein. This control of serotonin release by diet composition and of diet composition by serotonin is thought to have evolved becau it helps to sustain nutritional balance (Wurtman 1982).

Brain serotonin and brain tryptophan levels are found to depend mainly on two factors: first, they vary directly with plasm or serum tryptophan levels (including both "free" and albumin-bound), (see Figure 1); secondly, they vary inversely with the in grated plasma concentrations of the other large amino acids (LNAA creating a ratio of tryptophan/LNAA (Wurtman 1980). The LNAA (primarily leucine, isoleucine, valine, tyrosine, and phenylalani compete with tryptophan for passage across the blood-brain barrie (BBB) (Fernstrom and Wurtman 1972).

The determining factor involved in the tryptophan/LNAA ratio is the presence of carbohydrates. The ingestion of carbohydrates induces insulin secretion, which facilitates the uptake of the LNAA into muscle (Fernstrom and Wurtman 1972).

The determining factor involved in the tryptophan/LNAA ratio is the presence of carbohydrates. The ingestion of carbohydrates induces insulin secretion, which facilitates the uptake of the LN into muscle (Fernstrom and Wurtman 1971). If protein is added to the carbohydrate meal, a source of new tryptophan (and other amin acids) is introduced to the blood compartment (Fernstrom 1981). Since insulin does not reduce blood tryptophan concentrations, ingesting protein with carbohydrates increases blood tryptophan,

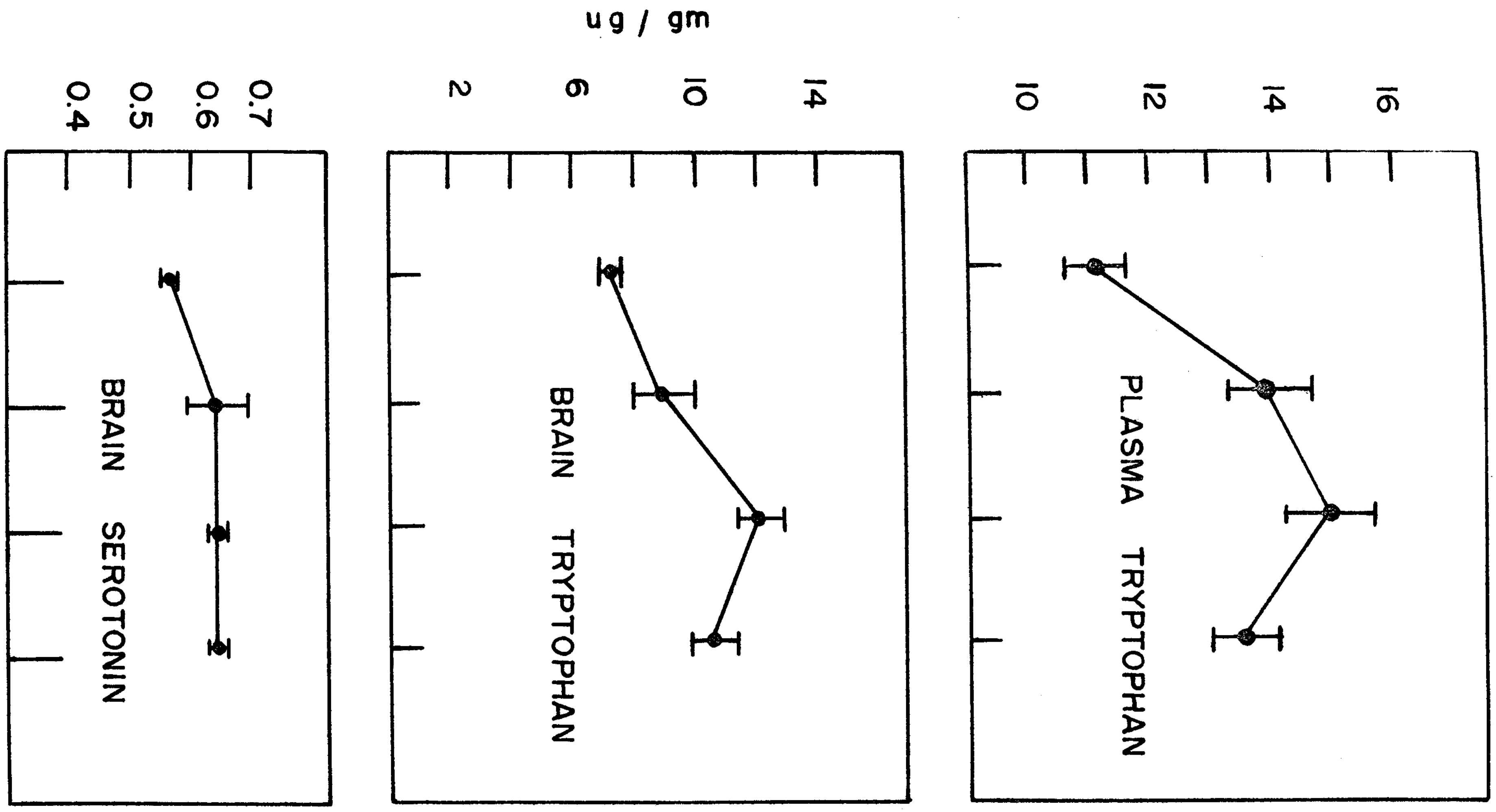

Figure 1. Effect of investing a carbohydrate meal on plasma and brain tryptophan, and brain serotonin levels in rats fasted over night. The values at 2 and 3 hr for each parameter are significantly elevated above control (i.e., fasted) levels. (Adapted from Fernstrom and Wortman 1973)

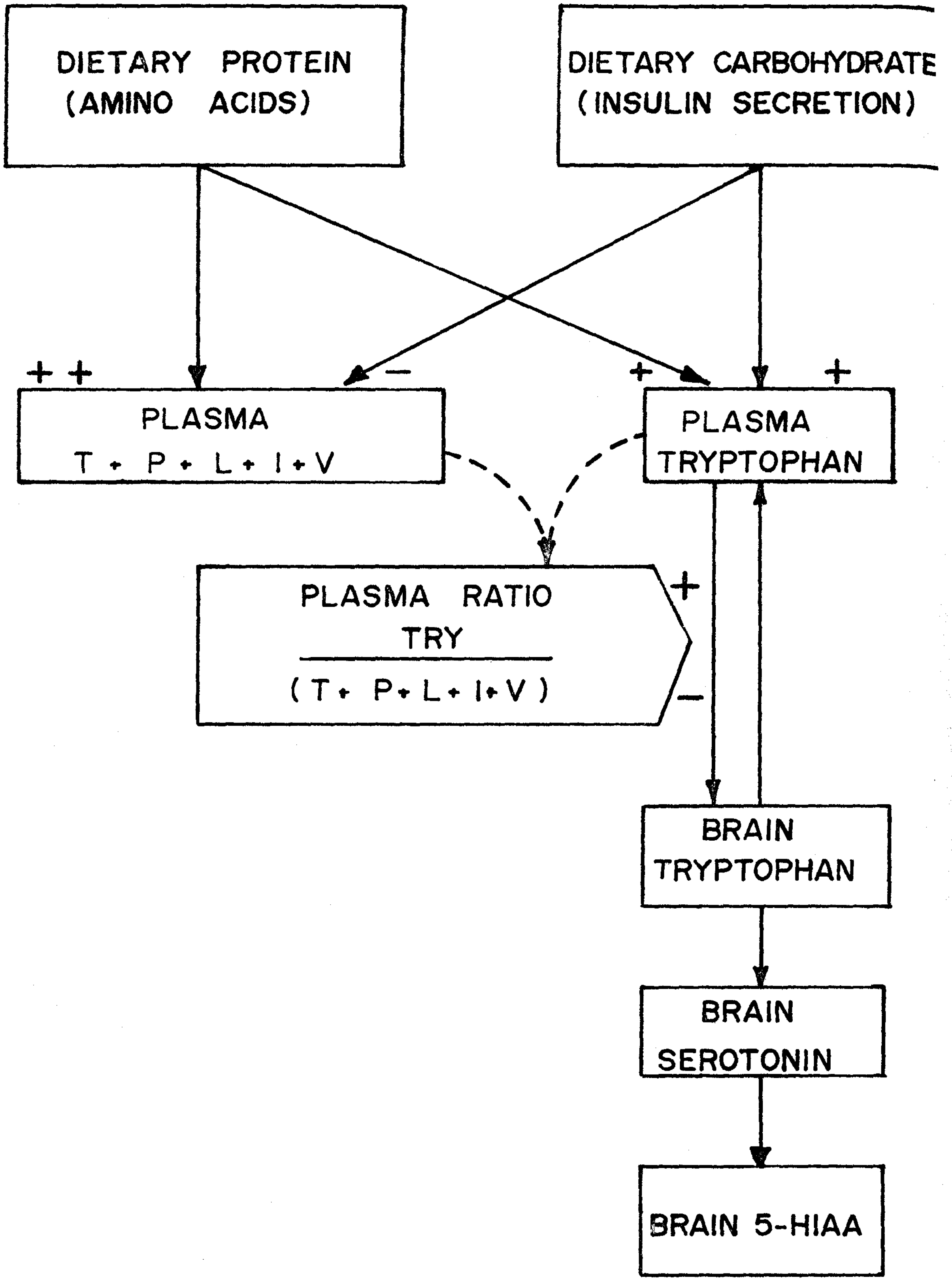

Figure 2. Proposed model to describe diet-induced changes in brain serotonin concentration. The ratio of total trytophan to the combined levels of tyrosine, phenylalanine, leucine, isoleucine, and valine in plasma i thought to predict trytophan levels in the brain. (Adapted from Fernstrom and Wurtman 1972).

ingesting protein with carbohydrates increases blood tryptophan, therefore increasing the levels of brain tryptophan and brain serotonin. It can now be said that dietary protein depresses the tryptophan?LNAA ratio, therefore having the most influence on brain tryptophan levels, and thereby slowing serotonin synthesis (Figure 2). On the other hand, the particular meal which most elevates brain tryptophan contains no tryptophan i.e., one lacking protein but rich in carbohydrates (Wurtman 1980).

I would now like to discuss the food and nutritional aspects of the indigenous peoples living in the South American Andes. In doing so I hope to correlate their dietary intake with factors affecting the synthesis of serotonin, in an attempt to understand their diet as an adaptive response to high altitude.

FOOD AND NUTRITION IN THE SOUTH AMERICAN ANDES

The Peruvian Andes can be divided into two major zones, the sierra and the puno. The sierra includes that land from near sea level to elevations up to 3200 m. In this area the climate allows the cultivation of a variety of cereals, tubers and legumes, and in the lower valleys, sugar cane, coffee, cacao, and bananas. The contemporary peoples of this zone are largely engaged in agricultural labor as well as cattle and swine husbandry (Picon-Reategui 1976).

The other zone, the puna, can be divided into two subzones: 1) the 'jalco' of the northern Peruvian Andes, beginning at 3200 m and consisting of only natural pasture; and 2) the 'true puna' of the central and southern Peruvian Andes, beginning at 3800 m. Due to the harsh environmental conditions and terrain of this area, only tubers and cereal-like goosefoot plants of the *Chenop* genus can be cultivated. The main economic activities in this s zone include mining, and llama, alpaca, and sheep herding with agriculture as a subsidiary activity (Picon-Reategui 1976).

It is important to bear in mind that the distinct life zone are closely interconnected, both ecologically and econominally (Table 1). Enrique Maybe (1979) describes this interrelationshi with respect to the Mantaro Valley, found in central Peru east o Lima, as such:

> The nival region provides water for irrigation in lower parts. The grassland areas of the alpine rain tundra, which support llama and alpaca herds, will provide meat and fiber for the clothing of inhabitants of the lower valley as well as means of transportation and animal manure for their crops. The lower areas in turn provide the higher areas with grain (particularly maize) and temperate fruits and vegetables. Seed from intermediate zones is often exchanged for seed produced in the low zones pasture animals spend periods of time grazing in the high zone and are brought down periodically to graze on the stubble of harvested fields or when they are needed for plowing.
>
> Exchange between zones is favored by the short distances between them, and also by the fact that each zone supports a specific set of crops and livestock. Exchange between the zones links them in one overall agricultural system, and gives the Mantaro Valley a strong regional character (Mayer, 1979:33).

The most complete surveys concerning diet and nutrition in Andes have been done by Mazess and Baker (1964) and Gursky (1969 The surveys concerned the Quechua-speaking Indians of Peru. Bot surveys concluded that the FAOs model with regard to calorie requirements, were in the positive direction. The problems involved in these surveys included the distribution of surplus food by a local priest during Gursky's survey so that the natives would qualify for supplemental aid and the season in which they were conducted.

When correlating the diet to high altitude adaptations it becomes difficult to separate out the factors involving 1) the acquisition of food from outside sources, leading to variations dependent upon the economic capabilities of the group or individual; 2) the degree of introduction of non-indigenous plant foods; 3) the increase reliance on a cash-crop income; and 4) the increased sole dependence on llama, alpaca, and sheep herding as cash-food exchange for other needed food products. These factors and others all lead to discrepancies involving the acquisition of food resources. Thus the surveys presented msut be regarded as a summation of all the involved factors.

DIET COMPOSITION AND TRYPTOPHAN/SEROTONIN PRODUCTION

Both surveys concluded that about 85-90 percent of the total caloric intake came from foodstuffs of vegetal origin in the Nunoa area. According to Mazess and Baker (1964), tubers provided about 74.2 percent of the total caloric intake, making it their staple food. Fresh potatoes supplied 23.5 percent of the caloric intake while <u>chuno</u> <u>negro</u> comprised 49.5 percent. Chenopods comprised 10 percent of the caloric intake while cereals and animal

Table 1. Characteristics of the Life Zones in the Mantaro Valley (adapted from Mayer, 1979:32).

Ecological Zone (Holdrige)	Altitude m.	Climate (Thorntwaite 1948)	Natural Vegetation	Ecological Conditions	Agricultural Crops	Land-Use
1. <u>Tropical Nival</u> (Cordillera)		Very frigid/humid	Lichens and microorganisms	Most specialized and restricted very little life	None	-
2. <u>Tropical Alpine Rain Tundra</u> (Puna Alta)	4,500-4,650	Frigid-humid	Alpine flora	Very specialized high altitude adaptation and to grazing activity	None	-
3. <u>Tropical Wet Subalpine Paramo</u> (Puna Baja)	4,000-4,650	Semi-frigid Subhumid	Gramineous grasses	Good grazing but specialized for high altitude agricultural crops	Papa shiri, mauna, barley in sheltered areas	Most land extensive marginal agriculture
4. <u>Tropical Montane Moist Forest</u> (Sierra Alta)	3,500-4,000	Cold-moist	Grasses and shrubs	More generalized environment	Potatoes, Andean tubers, European grains, habas, field peas, lupinus, quinua, onions	Less land extensive agriculture

habas, field
peas, lupinus,
quinua, onions

Table 1. Characteristics of the Life Zones in the Mantaro Valley (adapted from Mayer, 1979:32); continued

Ecological Zone (Holdrige)	Altitude m.	Climate (Thorntwaite 1948)	Natural Vegetation	Ecological Conditions	Agricultural Crops	Land-Use
5. <u>Tropical Montane Dry Forest</u> (Sierra)	3,000-3,500	Temperate semiarid	Grasses, shrubs & trees	Most generalized in study area	Potatoes, Andean tubers, European grains, habas, field peas, quinua, onions PLUS maize, clover, alfalfa, varied horticulture temperate fruit trees, etc.	Most land intensive diversified agriculture

foods produced 9.9 and 3.9 percent, respectively. The total cal intake for the area surveyed varied from a mean of 1784 kcal./pe person/per day (Gursky 1969) to 2110 kcal./per person/per day (B and Mazess 1964) for the same village of Nunoa. Factors leading these differences were attributed to the season of the survey, t change in economic position, and methods of analysis (Picon-Reategui 1976).

Only about 21.9 percent of the total protein in their diet of animal origin, 17.0 percent of the protein came from chenopdi 10.9 percent from cereals and 49.7 percent from tubers, making t largest percent of protein coming from vegetable origin (Baker a Mazess 1964). Protein consumption (Table 2) was about 69g/perso i.e., somewhat more than 1.0 g/Kg at body weight for the standar adult of Nunoa (Picon-Reategui 1976).

Metabolic balalnces suggest that the high altitude environm has no effect on protein requirements or on the absorption of pr teins. Dietary proteins also provide an adequate mixture of ami acids to ensure body maintenance. With this in mind, the amount of protein present probably proves to be adequate for the availability of tryptophan for ingestion. It is interesting to note in one of their prepared foods, *mote* (boiled corn from which the hulls have been previously removed by either calcium oxide or as in the water), a combination of beans is often cooked with it. high content of tryptophan in beans supplements the low content tryptophan in corn (Picon-Reategui 1978).

The diet of these high altitude populations compared to Euro pean and American populations is high in carbohydrates low in fat Surveys by Picon-Reategui show that 79 percent of the caloric int

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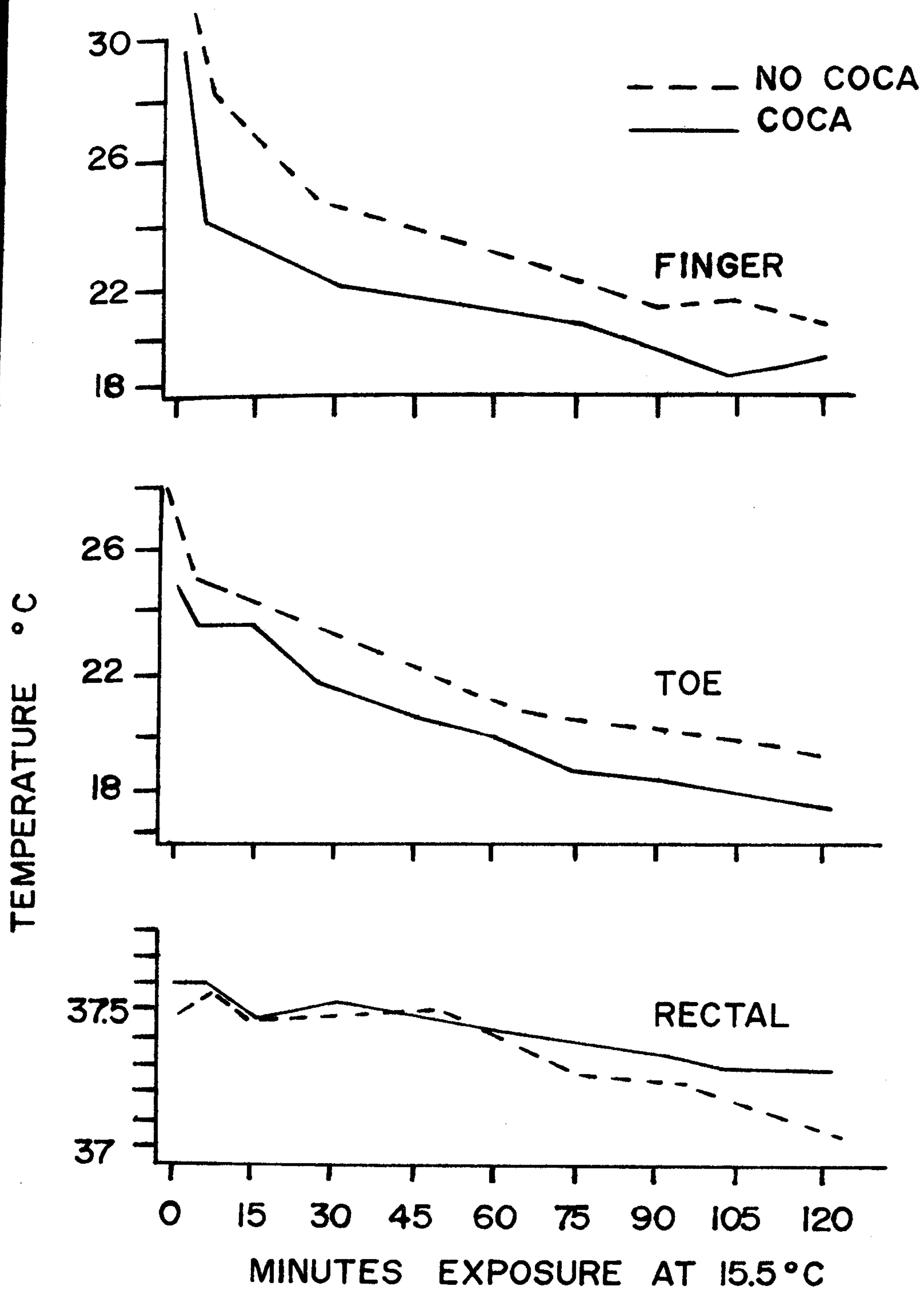

Figure 3. Effects of coca on body temperature (Hanna 1976:371)

Table 2.

Foods	Bulk (1,547 gm)	Calories (3,170)	Protein (69 gm.)	Fat (16 gm.)	Carbohydrate (696 gm)
Tubers					
Chuno negro	30.4	49.5	27.2	5.8	54.0
Potatoes	47.9	23.5	21.8	16.9	24.0
Other tubers	1.8	1.2	0.7	1.4	1.3
Subtotal	80.1	74.2	49.7	24.1	79.8
Cereals					
Barley	3.1	5.7	5.8	5.9	5.8
Maize	1.6	2.5	2.9	0.4	2.5
Wheat	0.9	1.7	2.2	2.2	1.5
Subtotal	5.9	9.9	10.9	8.5	9.9
Chenopodia					
Quinua	3.0	5.1	7.9	13.3	4.5
Canihua	2.9	4.9	9.1	12.5	4.2
Subtotal	5.9	10.0	17.0	25.8	8.7
Animal foods					
Meat	6.0	2.8	21.1	17.0	...
Cobo, or fat	0.3	1.1	0.5	22.9	...
Subtotal	6.3	3.9	21.9	39.9	...
Others*	1.8	2.0	0.4	1.7	2.2

Note: Figures in parentheses represent the average amount pe
person. * This includes onion, sugar, peppers and mil
(adapted from Mazess and Baker, 1964).

gm.)	Carbo- hydrate (696 gm
	54.0
	24.0
	1.3
	79.8
	5.8
	2.5
	1.5
	9.9
	4.5
	4.2
	8.7
	...
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	...
	2.2

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covered by carbohydrates, 12 percent by proteins, and 9 percent fat (Picon-Reategui 1978). Mazess and Baker (1964) showed an erage intake of 696 gm of carbohydrates, correlating with 69 gm. protein and 16 gm. of fat, at a caloric intake of 3170 (Table 2).

Picon-Reategui (1978) states that it is not known whether this et pattern is due to socioeconomic conditions or an adaptive se-ection to life at high altitudes. He goes on to mention that from theoretical point of view, it can bepostulated that a postulated at a carbohydrate rich meal maybe most adequate for an hypoxic vironment. Because the molecule of carbohydrate is already oxi-ized, it uses less oxygen in its metabolism than either proteins r fats. It has also been pointed out that the necessity of a high arbohydrate consumption at high altitudes is in order to maintain high level of carbon dioxide. High carbon dioxide production elps avoid an acid base disequilibrium (Velasquez 1972 in Picon-eategui 1978).

This may be true but one must also consider the great abundance f carbohydrates in the diet which will lead to increased insulin evels. This increase allows the LNAA to be taken up into the uscle and tryptophan to be readily available in the bloodstream or synthesis into serotonin (5-HT). This process will make serotonin 5-HT) more available to the brain.

With the preceeding in mind, the next section will deal with daptations to cold stress and processes through which coca chewing nd serotonin (5-HT) are involved in the thermoregulation of the ndean peoples.

THE AFFECTS OF COCA CHEWING AND SEROTONIN IN THERMOREGULATION

The technological adaptations to cold stress in the Andes h led to native clothing providing a comfortable thermal environme for most of the body. So important is clothing that it is used during sleep. Native houses of adobe or stone seem to be of min importance when considering the relative ambient temperature differences, although they do provide an escape from wind chill factors, the elements, and long wave radiation heat loss at night (Hanna 1976).

The physiological adaptations to cold stress have been attr to many mechanisms including slightly elevated basal and resting metabolism, a warmer core temperature, and higher levels of bloo flow to the extremities, which results in warm limb surfaces and heat loss (Little 1976). Coca use during cold stress is said to produce a mild vasoconstriction, which is observed as lower fing and toe temperatures. The result is a reduced heat loss from th areas, and the heat conserved enables the coca user to maintain higher core temperature (Hanna 1976). It is important to note t one of the main functions of serotonin is its capacity to be a potent vasoconstricter (see Figure 3).

In the southern Peruvian Andes there are two periods of max cold exposure. The most severe period in terms of ambient tempe ture, radiation cooling, and aridity occurs from May through Aug This is the dry season and very little agricultural activity occ at this time (Little and Hanna 1978). The second period of cold the Andes occurs during the rainy season, which begins in Septem and lasts until April. Heavy winds with accompanying precipitat soak clothing and chill the body during activities out of doors rainy mornings or afternoons. The planting season (September-October) leads to long hours in the fields under cold, wet conditions (Little and Hanna 1978). There is strong evidence to demonstrate that coca chewing increases during these extreme periods of cold stress. However, I feel that there is another relation to thermoregulation involving the ingestion of calcium.

One of the most reliable sources of calcium in the Andes is obtained through the chewing of coca. Not from the actual coca leaves but from the additive _llipta_. To form _llipta_, the ashes of the stalks of two local grains, _quinua_ and _canihua_, are mixed with water to form a paste which is dried in the sun into small black cakes. A pinch from the cake is taken with every chew of coca (Baker and Mazess 1963). Along with the increase of coca chewing (therefore increasing the intake of calcium) during periods of cold or rainy weather increased calcium intake from animal products such as milk and cheese are used most heavily during the rainy season from December to April (Fuchs 1978).

The important physiological factor concerning calcium is that the change in the release of serotonin occurs as a result of excess calcium ions above that present in a normal physiological medium when involved in the process of thermoregulation in the anterior hypothalamus (Myer 1973). The anterior hypothalamus is the seat of thermoregulation. The theory of the serotonergic activations of hyperthermia includes the process through which serotonin is released presynaptically within the anterior hypothalamus which stimulates heat production (Myers 1973).

This series of physiological events has led me to believe that serotonin plays an important and specific role in the maintenance of inner core temperatures regarding the Andean peoples. With the dietary control of calcium at times of stress, they ha adaptively overcome one of the major limiting factors involved i high altitude living. Whether the effects of coca influences th process to any degree is hard to say. It may be that both the c and serotonin are interrelated in their function to produce the most adaptive physiological response, vasoconstriction.

It is now possible to see the importance of coca and seroto in one aspect of high altitude physiology. In the forthcoming section I would like to expand the uses of these two physiologic factors, and relate them to the high altitude adaptations involv in hypoxia.

POSSIBLE EFFECTS OF COCA ALKALOIDS AND SEROTONIN IN HYPOXIA

Man's natural physiologic adaptation to hypoxia (oxygen wan or deficiency) is the above normal increase in the number of red blood cells (or erythrocytes). This condition is called polycyt This function is due to the inverse correlation between the conc tration of hemoglobin in the peripheral blood and the percentage of 0_2 saturation occasioned by residence at high altitude. This indicates the existence of a precise mechanism for controlling hematopoieses in terms of 0_2 supply (Harris and Kellermeyer 1970 This mechanism is controlled by the negative feedback system act

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through a humoral factor, erythropoieten (see Figure 5). Erythropoietes, a gluco-protein which is formed primarily in the kidneys and the liver, stimulates increased red blood cell production in bone marrow (Garruto 1976).

While altitude polycythemia is purported to be adaptive, a number of functional disadvantages could offset the beneficial gains derived from such a response. One example is that in increase in erythrocyte concentration increases blood viscosity, thereby increasing blood flow resistance and work load on the heart. The polycythemic responses associated with these pathological conditions clearly do not indicate a physiological advantage under conditions of hypoxic stress (Garruto 1976).

Andrew Fuchs (1978) proposed that in the physical mechanisms associated with coca chewing, the antimuscarinic ingredients in the leaf act upon critical areas of the posterior hypothalamus to depress erythropoieses. By so doing, they are antagonists to the hypoxia which stimulates excessive red blood cell production. Thus, coca provides specific pharmacological relief for chronic hypoxia.

The relationship of polycythemic functions to tryptophan is still unknown. However, it is known that the variation of tryptophan concentrations in erythrocytes seem parallel plasma 'free' tryptophan. Tryptophan being bound to the circulating albumin and having a lower affinity for the erythrocytes than for the albumin, may be decreased by the lower levels of albumin found in coca chewers. It is also important to note that competition effects in

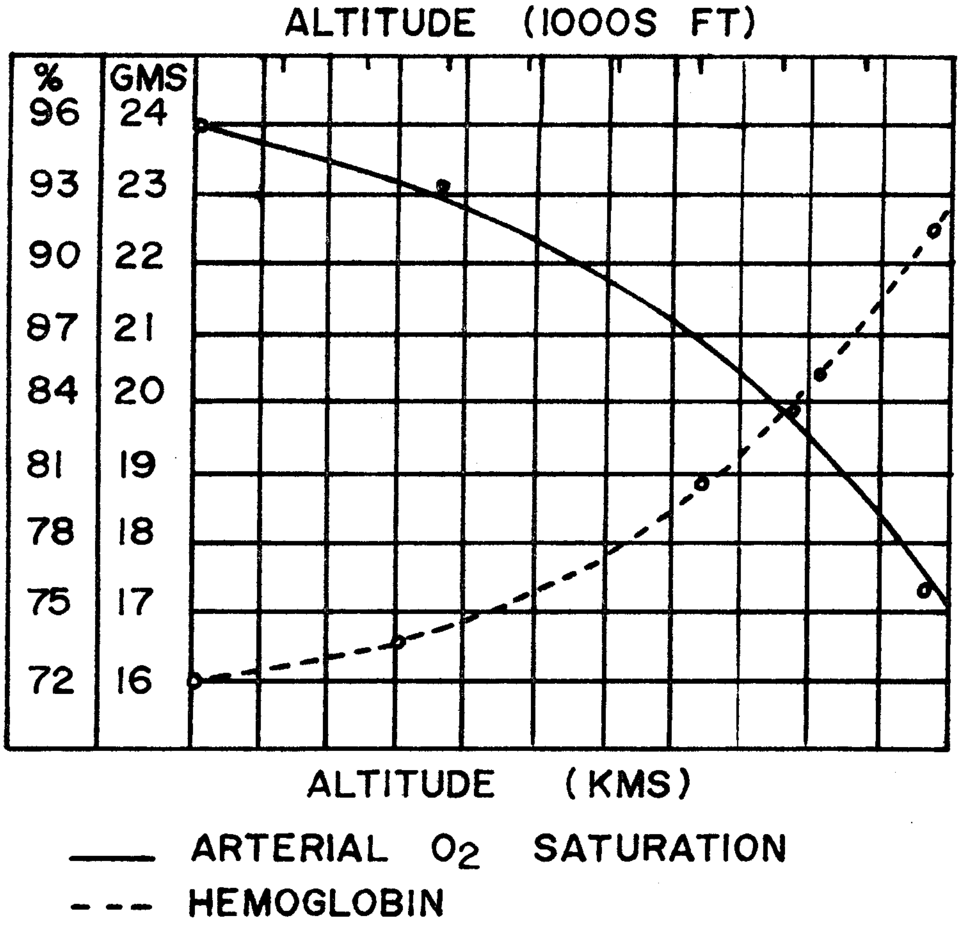

Figure 4. Correlation between concentration of hemoglobin in peripheral blood and percentage of oxygen saturation of atmosphere at various altitudes. (adapted from Harris and Kellermeyer 1970:371).

the tryptophan/LNAA ratio at the BBB are not expected to significantly affect tryptophan uptake by red blood cells, even though the capacity of LNAA transport into mammalian erythrocytes is ten fold higher than usual plasma amino acid concentrations (Wurtman and Pardridge 1979).

The limiting factor here is not necessarily the correlation between erythrocytes and tryptophan but in the process of tryptophan hydroxylation, mentioned earlier in the paper. Cerebral tryptophan hydroxylase appears to have poor affinity for oxygen and to be affected by slight hypoxia.

Another factor involving coca is that it may block the uptake of serotonin into the brain (Katz 1978). Yet, it has also been observed in the Andes that the chewing of coca leaves is more often than not accompanied by the ingestion of high carbohydrate food substances, which may possibly lead to increases in serotonin production.

The dilema seems to stem from the interrelationship of serotonin and coca. In many cases coca seems to have an adverse effect on the synthesis of serotonin. It may be possible to surmise that coca may have a regulatory effect on tryptophan and the synthesis of serotonin, thus enabling it to control the overproduction of serotonin which might lead to adverse effects.

Other characteristics of serotonergic neurons that might be related to high altitude stress including hypoxia and polycythemia might include their capacity to lower blood pressure through the modulating sympathic outflow. Included in this is their capacity to relieve pertension (Table 3). While coca is thought to have some effect in reducing pain or at least in the perception of i tryptophan availability has been correlated with producing mild analgesic effects, raising the pain and escape thresholds of animals (Fernstrom 1981).

Table 3. Effect of L-Tryptophan Injection on Blood Pressure in Hypertensive Rats

Dose (mg/kg)	blood pressure (mm Hg)
0	6 ± 3
25	11 ± 3
50	23 ± 5
100	28 ± 5

(adapted from Fernstrom 1981)

CONCLUSION

Through an examination of the dietary intake of some indigenous peoples of the South American Andes, I was able to present some relationships concerning the intake of carbohydrates with possible relating increases in the synthesis of serotonin. Increased serotonin production due to their high intake of carbohydrates proved to be a possible adaptive response to physiological thermoregulation controls. Coca and its calcium additive <u>llipta</u> also proved to be an important physiological response to periods of cold stress. When trying to find correlations to physiological adaptations involving the effects of hyoxia and polycythemia, coca proved to be a viable physiological response in the regulation of polycethemia due to the ensuing hypoxic stress. Serotonin, on the other hand, seemed to have a more predominant effect on the regulation of pain, blood pressure, and hypertension.

It is in my opinion that coca and the action of serotonergic neurons feasibly played an adaptive role in the Andean high altitude environment. The availability of tryptopan for synthesis into serotonin has also produced a unique correlation between the utilization of food resources and the resulting control of dietary intake.

It is important to note that a great deal of ideas expressed in this paper are under a great deal of controversy and are being subjected to close scrutiny. This is frequently the case in many scientific investigations. It is my intention here to suggest how human physiological functions need to be closely analyzed in te of evolutionary theory and adaptation. When one can attain thi through scientific processes, it is then possible to find addit relationships involved in correlation with mans cultural adaptations as well as leading into the overall holistic goal in the anthropological context. In the contemporary world of anthropo it is essential that empirical scientific data and cultural dat go hand in hand to form any conclusions in the context of man.

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